CLAIMS

Having thus described our invention in detail, what we claim as new and desire to secure by the Letters Patent is:

1. A porous, low-k dielectric film comprising:

a first phase of monodispersed pores having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially located on sites of a three-dimensional periodic lattice; and

a second phase surrounding said first phase, wherein said second phase is a solid phase which includes (i) an ordered element that is composed of nanoparticles having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially arranged on sites of a three-dimensional periodic lattice, and (ii) a disordered element comprised of a dielectric material having a dielectric constant of less than about 2.8.

2. The porous, low-k dielectric film of Claim 1 wherein said nanoparticles are comprised of Si, C, O and H.

3. The porous, low-k dielectric film of Claim 1 wherein said film has an effective dielectric constant of less than about 2.0.

4. The porous, low-k dielectric film of Claim 1 wherein said film has an effective dielectric constant of about 1.8 or less.

5. The porous, low-k dielectric film of Claim 1 wherein said monodispersed pores have a diameter of from about 1 to about 5 nm.

6. The porous, low-k dielectric film of Claim 5 wherein said monodispersed pores have a diameter of about 3 nm.

7. The porous, low-k dielectric film of Claim 1 wherein said pores are separated by a center-center distance V_{cc}.

8. The porous, low-k dielectric film of Claim 7 wherein V_{cc} between each pore is from about 2 to about 10 nm.

9. The porous, low-k dielectric film of Claim 8 wherein V_{cc} between each pore is from about 3 to about 6 nm.

10. The porous, low-k dielectric film of Claim 1 wherein said pores are separated by an edge-edge distance V_{ee}.

11. The porous, low-k dielectric film of Claim 10 wherein V_{ee} between each pore is from about 1 to about 8 nm.

12. The porous, low-k dielectric film of Claim 11 wherein V_{ee} between each pore is from about 2 to about 5 nm.

13. The porous, low-k dielectric film of Claim 1 wherein said pores and said nanoparticles are separated by a distance AB.

14. The porous, low-k dielectric film of Claim 13 wherein AB is from about 1 to about 10 nm.

15. The porous, low-k dielectric film of Claim 14 wherein AB is from about 2 to about 50 nm.

16. The porous, low-k dielectric film of Claim 1 wherein said nanoparticles have a diameter of from about 2 to about 3.0 nm.

17. The porous, low-k dielectric film of Claim 1 wherein said low-k dielectric binder has a dielectric constant of about 2.8 or less.

18. The porous, low-k dielectric film of Claim 1 wherein said low-k dielectric binder is selected from the group consisting of polyarylene ethers, thermosetting polyarylene ethers, aromatic thermosetting resins, Si-containing polymers, amorphous alloys comprised of Si, C, O and H that may, or may not, be doped with oxide, methylsilsesquioxane (MSQ), hydrogensilsesquioxane (HSQ), phenylsilsesquioxane (PSQ), and mixtures or complexes thereof.

19. The porous, low-k dielectric film of Claim 18 wherein said low-k dielectric binder is MSQ, HSQ, PSQ or a mixture of MSQ and HSQ.

20. The porous, low-k dielectric film of Claim 1 wherein said film has a hardness of about 0.2 GPa or greater.

21. The porous, low-k dielectric film of Claim 20 wherein said film has a hardness of from about 0.2 to about 0.4 GPa.

22. The porous, low-k dielectric film of Claim 1 wherein said film has a Modulus of about 2.0 GPa or greater.

23. The porous, low-k dielectric film of Claim 22 wherein said film has a Modulus of from about 2 to about 4 GPa.

24. An interconnect structures which includes at least a porous, low-k dielectric film formed between metal wiring features, wherein said porous, low-k dielectric film

comprises a first phase of monodispersed pores having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially located on sites of a three-dimensional periodic lattice; and a second phase surrounding said first phase, wherein said second phase is a solid phase which includes (i) an ordered element that is composed of nanoparticles having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially arranged on sites of a three-dimensional periodic lattice, and (ii) a disordered element comprised of a dielectric material having a dielectric constant of about 2.8 or less.

25. The interconnect structure of Claim 24 wherein said nanoparticles are comprised of Si, C, O and H.

26. The interconnect structure of Claim 24 wherein said film has an effective dielectric constant of less than about 2.0.

27. The interconnect structure of Claim 26 wherein said film has an effective dielectric constant of about 1.8 or less.

28. The interconnect structure of Claim 24 wherein said monodispersed pores have a particle diameter of from about 1 to about 5 nm.

29. The interconnect structure of Claim 24 wherein said monodispersed pores have a particle diameter of about 3 nm.

30. The interconnect structure of Claim 24 wherein said pores are separated by a center-center distance V_{cc}.

31. The interconnect structure of Claim 30 wherein V_{cc} between each pore is from about 2 to about 10 nm.

32. The interconnect structure of Claim 31 wherein V_{cc} between each pore is from about 3 to about 6 nm.

33. The interconnect structure of Claim 24 wherein said pores are separated by an edge-edge distance V_{ee}.

34. The interconnect structure of Claim 33 wherein V_{ee} between each pore is from about 1 to about 8 nm.

35. The interconnect structure of Claim 34 wherein V_{ee} between each pore is from about 2 to about 5 nm.

36. The interconnect structure of Claim 24 wherein said pores and said nanoparticles are separated by a distance AB.

37. The interconnect structure of Claim 36 wherein AB is from about 1 to about 10 nm.

38. The interconnect structure of Claim 37 wherein AB is from about 2 to about 5 nm.

39. The interconnect structure of Claim 24 wherein said nanoparticles have a diameter of from about 2 to about 3.0 nm.

40. The interconnect structure of Claim 24 wherein said low-k dielectric binder has a dielectric constant of about 2.8 or less.

41. The interconnect structure of Claim 24 wherein said low-k dielectric binder is selected from the group consisting of polyarylene ethers, thermosetting polyarylene ethers, aromatic thermosetting resins, Si-containing polymers, amorphous alloys comprised of Si, C, O and H that may, or may not, be doped with oxide,

methylsilsesquioxane (MSQ), hydrogensilsesquioxane (HSQ), phenylsilsesquioxane (PSQ), and mixtures or complexes thereof.

42. The interconnect structure of Claim 41 wherein said low-k dielectric binder is MSQ, HSQ, PSQ or a mixture of MSQ and HSQ.

43. The interconnect structure of Claim 24 wherein said metal wiring features are metal lines or vias.

44. The interconnect structure of Claim 24 wherein said metal wiring features are composed of a conductive metal selected from the group consisting of Cu, Al, W, Pt and alloys or combinations thereof.

45. The interconnect structure of Claim 24 further comprising a substrate.

46. The interconnect structure of Claim 45 wherein said substrate is a semiconductor wafer, a dielectric layer, a barrier layer or a combination thereof.

47. The interconnect structure of Claim 24 wherein said structure is a dual damascene structure.

48. The interconnect structure of Claim 24 wherein said structure is a gapfill structure.

49. A method of fabricating a porous, low-k dielectric film comprising the steps of:

(a) coating a suspension of water soluble or water vapor soluble oxide particles with a surface ligand group which is effective in preventing agglomeration of said water soluble or water vapor soluble oxide particles, yet maintains solubility of the oxide

particles in said suspension, while separating forming monodispersed SiCOH particles having a particle diameter of from about 1 to about 10 nm;

(b) adding said coated water soluble or water vapor soluble oxide particles and said monodispersed particles to a solution containing a dielectric binder material having a dielectric constant of about 2.8 or less so as to form a precursor mixture;

(c) coating said precursor mixture on to a surface of a substrate;
(d) subjecting said coated precursor mixture to a curing process, said curing process including at least a step which is capable of ordering of said particles in a three-dimensional lattice and a step of forming a crosslinked film;

(e) removing said coated water soluble or water vapor soluble oxide particles from said crosslinked film so as to form pores in said film; and

(f) annealing said film containing said pores so as to remove residual water and hydroxyl groups from said film, wherein said film comprises a first phase of monodispersed pores having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially located on sites of a three-dimensional periodic lattice; and a second phase surrounding said first phase, wherein said second phase is a solid phase which includes (i) an ordered element that is composed of nanoparticles having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially arranged on sites of a three-dimensional periodic lattice, and (ii) a disordered element comprised of said binder.

50. The method of Claim 49 wherein said monodispersed particles are comprised of Si, C and H and said nanoparticles are comprised of Si, C, O and H.

51. The method of Claim 49 wherein said oxide particles are silicon oxide, germanium oxide, or mixtures thereof.

52. The method of Claim 49 wherein said suspension includes a solvent selected from the group consisting of an alcohol, an alkane, a ketone, an ether, an aromatic, and a carboxylic acid.

53. The method of Claim 49 wherein said surface ligand group is selected from the group consisting of an organosilane, an organohalosilane, germanium analogs of said organosilane or organohalosilane, long chain carboxylic acids containing from 4 to 18 carbon atoms, long chain alcohols containing from 4 to 18 carbon atoms, long chain alkylamines containing from 4 to 18 carbon atoms, long chain phosphonic acids containing from 4 to 18 carbon atoms, and long chain sulfonic acids containing from 4 to 18 carbon atoms.

54. The method of Claim 49 wherein said dielectric binder is selected from the group consisting of polyarylene ethers, thermosetting polyarylene ethers, aromatic thermosetting resins, Si-containing polymers, amorphous alloys comprised of Si, C, O and H that may, or may not, be doped with oxide, methylsilsesquioxane (MSQ), hydrogensilsesquioxane (HSQ), phenylsilsesquioxane (PSQ), and mixtures or complexes thereof.

55. The method of Claim 54 wherein said dielectric binder is MSQ, HSQ, PSQ or a mixture of MSQ and HSQ.

56. The method of Claim 49 wherein said coating step is a spin-coating process.

57. The method of Claim 49 wherein said curing process includes an optional hot bake process.

58. The method of Claim 57 wherein said optional hot bake process is carried out on a hot plate in air at a temperature of from about 80° to about 200°C for a time period of from about 1 to about 10 minutes.

59. The method of Claim 49 wherein said ordering curing step is carried out in a furnace using an inert ambient that includes less than about 50 ppm O_2 or H_2O.

60. The method of Claim 59 wherein said ordering curing step is carried out at a temperature of from about 200° to about 300°C for a time period of from about 30 to about 120 minutes.

61. The method of Claim 49 wherein said crosslinking curing step is carried out at a temperature of from about 350° to about 450°C for a time period of from about 60 to about 240 minutes.

62. The method of Claim 49 wherein step (e) includes immersing said crosslinked film in water or exposing said crosslinked film to water vapor.

63. The method of Claim 49 wherein said annealing step out in a furnace using an ambient that includes less than about 50 ppm O_2 or H_2O.

64. The method of Claim 63 wherein said annealing step is carried out at a temperature of from about 200° to about 400°C for a time period of from about 60 to about 240 minutes.

65. The method of Claim 49 wherein step (a) includes injecting 1 to 5 weight % of a solution containing a silicon precursor into a hot solution containing said surface ligand and an organic solvent containing between 0.1 to1 % water.

66. The method of Claim 65 wherein said silicon precursor is a siloxane or a silsesquioxane.